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DRAFT Recommended Practice for Measurement of Gaseous and Particulate Emissions from Heavy Duty Diesel Engines Under Transient Conditions

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Recommended Practice for Measurement of Gaseous and Particulate Emissions from Heavy-Duty Diesel Engines Under Transient Conditions

by

Eugene Danielson

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16. ABSTRACT

This document describes the equipment required and the procedures to be followed in measuring exhaust emissions from heavy-duty diesel engines. For clarity and continuity this document is structured to be totally compatible with the proposed heavy-duty gaseous emission regulations (Federal Register, Vol. 44, No. 31, February 13, 1979). It should be noted that (1) this procedure does not negate or adversely affect the proposed heavy-duty regulations, but merely specifies the additional equipment and steps necessary for diesel particulate testing; and (2) this format incorporates diesel particulate testing for the 1983 and later model years. Sections in the proposed heavy-duty gaseous emission regulations which are affected by the incorporation of particulate testing are included in this recommended practice. A vertical line in the left margin indicates that a change to the proposed regulations has been made on the adjacent line of the text. The specific changes are enclosed in brackets.

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General Introduction

This document describes the equipment required and the procedures to be followed in measuring exhaust emissions from heavy-duty diesel engines. For clarity and continuity, this document is structured to be totally compatible with the proposed heavy-duty gaseous emission regulations (Federal Register, Vol. 44, No. 31, February 13, 1979).

It should be specifically noted that (1) this procedure does not negate or adversely affect the proposed heavy-duty regulations, but merely specifies the additional equipment and steps necessary for diesel particulate testing; and (2) this format incorporates diesel particulate testing for the 1983 and later model years. Sections in the proposed heavy-duty gaseous emission regulations which are affected by the incorporation of particulate testing are included in this recommended practice. A vertical line in the left margin indicates that a change to the proposed regulations has been made on the adjacent line of the text. The specific changes are enclosed in brackets, [], as an aid to the reader.

The most noteworthy concepts of this test procedure are summarized in the paragraphs below.

This recommended practice specifies that particulate and regulated gaseous emissions be measured simultaneously over the same transient cycle (§86.1310 and §86.1327). The test procedure requires a primary-dilution tunnel and a constant volume sampler (§86.1310). It is optional as to whether or not a secondary-dilution tunnel (i.e., double dilution) is to be used (§86.1310). Inlet depression and exhaust backpressure limits are specified (§86.1308). (NOTE: These specifications include gasoline-fueled engines.) Particulate samples are collected on a filter media operating at a maximum temperature of 125°F (51.7°C) (§86.1310). Total hydrocarbons are measured continuously through a heated probe installed in the primary-dilution tunnel. Specific operating ranges are required for the HFID analyzer (§86.1338). The complete HC sample system is operated at a nominal 375°F (§86.1310). Bagged emissions (CO, CO2 and NOx) are collected in the constant volume bag as defined in the proposed regulations (§86.1310 and §86.1327).

Two particulate samples are taken. A cold start sample is collected during the cold-start transient cycle, and a hot-start sample is collected during the hot-start transient cycle (§86.1327). Filters are weighed on a microgram balance in a controlled ambient weighing room (§86.1312).

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* = Sections contained in this document. For other sections see "1983 and Later Model Year Heavy-Duty Engines," FR Part II 02/13/79 (pages 9499 through 9539).

§86.1301-83 Scope; applicability.

This subpart contains the gaseous emission test procedures for gasoline-fueled [heavy-duty engines and the gaseous and particulate emission test procedure for heavy-duty diesel engines.] It applies to 1983 and later model years.

§86.1302-83 Definitions.

[(a)] The definitions in Subpart A apply to this subpart.

[(b) "Particulate" is any material (excluding condensed water) collected by filtering a sample of diluted exhaust. Both the filter and the exhaust stream from which the sample is taken must be at or below a temperature of 125°F (52.2°C).]

§86.1308-83 Dynamometer and engine equipment specifications.

(a) Engine dynamometer.

(1) The engine dynamometer system must be capable of transiently controlling engine torque and rpm, simultaneously on a transient cycle. The transient torque and rpm schedules listed in §86.1315 and Appendix I (f and g) must be followed within the accuracy requirements specified in §86.1315. In addition to these general requirements, the dynamometer shall meet the following accuracy specifications:

(i) Engine speed shall be accurate to within 2 percent of point at all speeds.

(ii) Engine torque at the flywheel shall be accurate to within 3 percent of point at all torque settings above 10 percent of full scale. Below 10 percent of full scale the accuracy shall be within 5 percent of point.

(2) Dynamometer calibration weights. A minimum of 6 calibration weights for each range used are required. The weights must be equally spaced and accurate to 0.5 percent of NBS weights. Laboratories located in foreign countries may certify calibration weights to local government bureau standards.

[(b) Engine equipment.

(1) Engine cooling. Means of engine cooling which will

maintain the engine operating temperatures (e.g., intake air, oil, water, etc.) at approximately the same temperature as specified by the manufacturer shall be used. Auxiliary fan(s) may be used to maintain engine cooling during operation on the dynamomter.

(2) Inlet system.

(i) Gasoline engines.

(A) The inlet pressure shall typify the in-use level as specified in §86.1342.

(B) A chassis-type inlet system shall be used.

(ii) Diesel engines. The inlet pressure shall be controlled to the manufacturer's typical limit as specified in §86.1342. This may be accomplished by using a butterfly valve.

(3) Exhaust system.

A stabilizied (with respect to emissions) chassis-type exhaust system shall be used. The exhaust system shall meet the following requirements:

(i) Length.

(A) The distance from the exhaust manifold flange to the exit of the chassis exhaust system shall be the same as the minimum distance measured in the in-use applications of the

engine (for diesels only).

(B) For all catalyst systems, the distance from the exhaust manifold flange(s) to the catalyst shall be the same as in the vehicle configuration unless the manufacturer provides data showing equivalent performance at another location.

(ii) Back pressure.

(A) For gasoline engines, the exhaust back pressure shall typify those seen in the actual vehicle exhaust system configuration.

(B) For diesel engines, the exhaust back pressures shall typify those measured in the maximum back pressure application of the engine.]

§86.1309-83 Exhaust gas sampling system; [gasoline-fueled vehicles.]

(a)(1) General. The exhaust gas sampling system is designed to measure the true mass emissions of engine exhaust. In the CVS concept of measuring mass emissions, two conditions must be satisfied; the total volume of the mixture of exhaust and dilution air must be measured, and a continuously proportioned sample of volume must be collected for analysis. Mass emissions are determined from the sample concentration and total flow over the test period.

(2) Positive displacement pump. The positive displacement pump - constant volume sampler (PDP-CVS), Figure N83-1, satisfies the first condition by metering at a constant temperature and pressure through the pump. The total volume is measured by counting the revolutions made by the calibrated positive displacement pump. The proportional sample is achieved by sampling at a constant flow rate.

(3) Critical flow venturi. The operation of the critical flow venturi - constant volume sampler (CFV-CVS), Figure N83-2, is based upon the principles of fluid dynamics associated with critical flow. Proportional sampling throughout temperature excursions is maintained by use of a small CFV in the sample line. The variable mixture flow rate is maintained

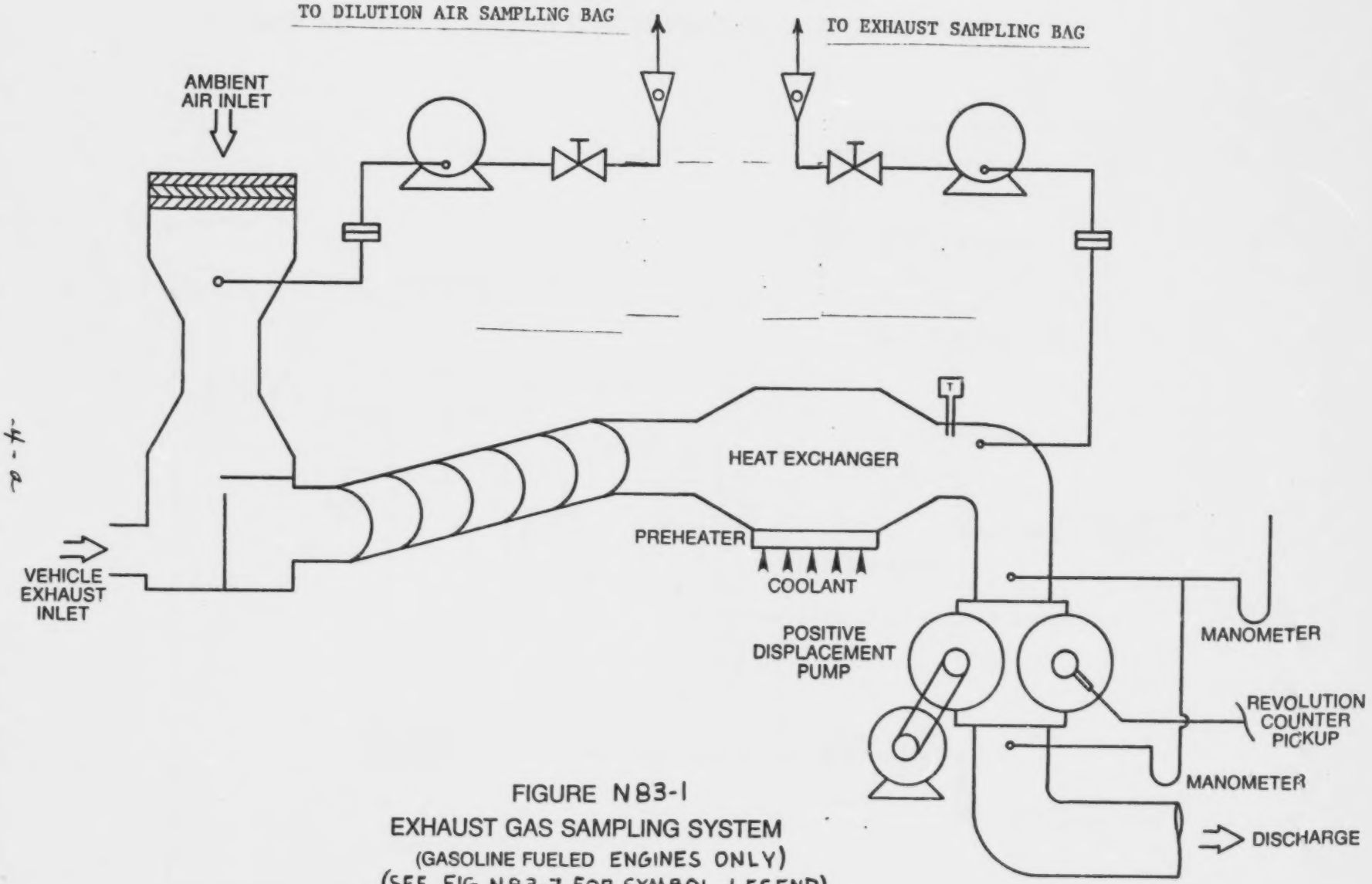

FIGURE N83-1
EXHAUST GAS SAMPLING SYSTEM
(GASOLINE FUELED ENGINES ONLY)
(SEE FIG. N83-7 FOR SYMBOL LEGEND)

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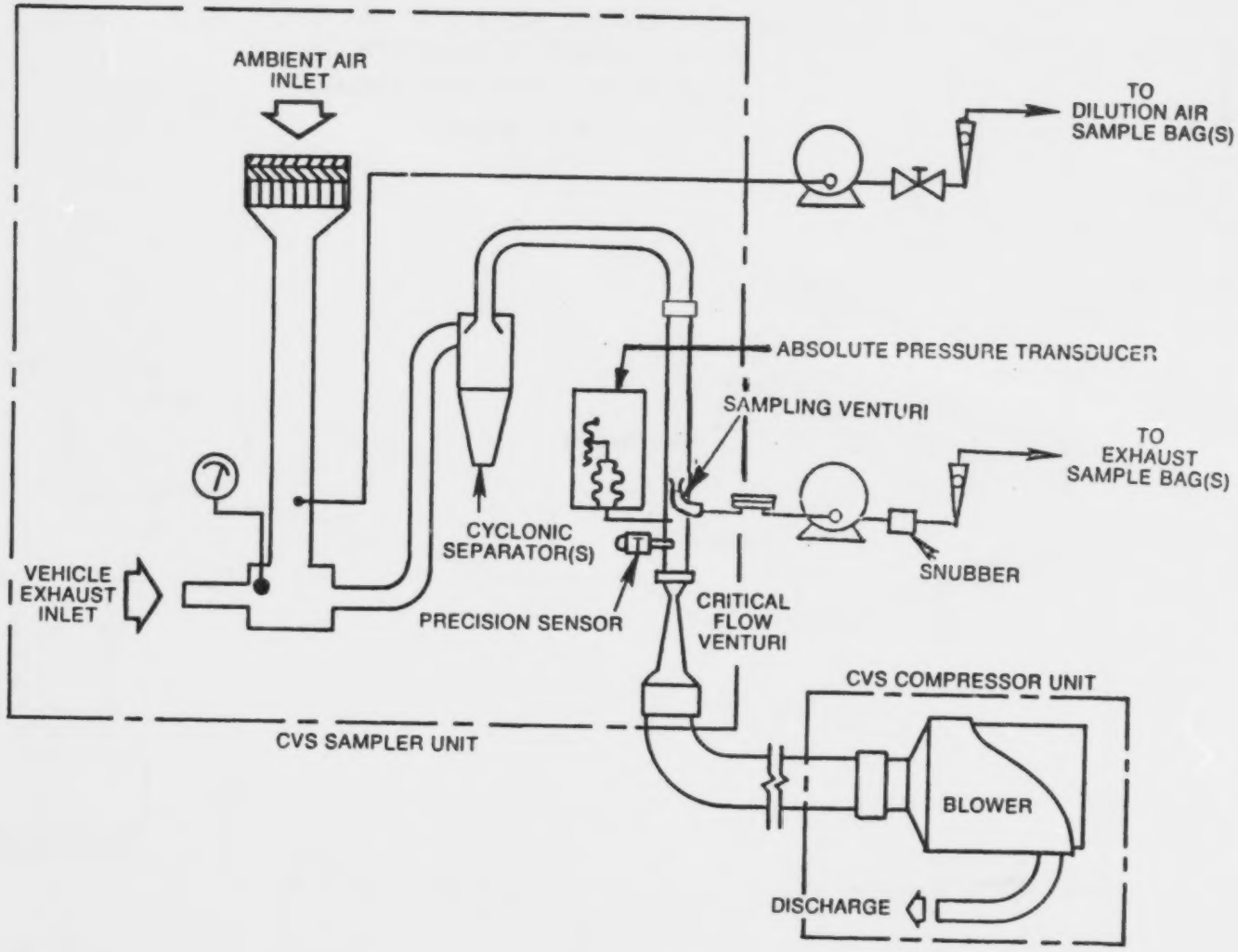

FIGURE N83-2 EXHAUST GAS SAMPLING SYSTEM (CFV-CVS)
(GASOLINE FUELED ENGINES ONLY)
(SEE FIGURE N83-7 FOR SYMBOL LEGEND)

at sonic velocity, which is directly proportional to the square root of the gas temperature, and is computed continuously. Since the pressure and temperature are the same at both venturi inlets, the sample volume is proportional to the total volume.

(4) Other systems. Other sampling systems may be used if shown to yield equivalent results, and if approved in advance by the Administrator.

(b) Component description, PDP-CVS. The PDP-CVS, Figure N83-1, consists of a dilution air filter and mixing assembly, heat exchanger, positive displacement pump, sampling system, and associated valves, pressure and temperature sensors.

The PCP-CVS shall conform to the following requirements:

(1) Static pressure variations at the tailpipe(s) of the engine shall remain within ± 5 inches of water (± 1.2 kPa) of the static pressure variations measured during a dynamometer engine cycle with no connection to the tailpipe(s). (Sampling systems capable of maintaining the static pressure to within ± 1 inch of water (± 0.25 kPa) will be used by the Administrator if a written request substantiates the need for this closer tolerance.)

(2) The gas mixture temperature, measured at a point immediately ahead of the positive displacement pump, shall be within ± 10°F (5.6°C) of the designed operating temperature at the start of the test. The gas mixture temperature variation from its value at the start of the test shall be limited to ± 10°F (5.6°C) during the entire test. The temperature measuring system shall have an accuracy and precision of ± 2°F (1.1°C).

(3) The pressure gauges shall have an accuracy and precision of ± 1.6 inches of water (0.4 kPa).

(4) The flow capacity of the CVS shall be large enough to eliminate water condensation in the dilution system, as well as in the gas sampling system.

(5) Sample collection bags for dilution air and exhaust samples shall be of sufficient size so as not to impede sample flow.

(c) Component description, CFV-CVS. The CFV-CVS, Figure N83-2 consists of a dilution air filter and mixing assembly, cyclone particulate separator(s), sampling venturi, critical flow venturi, sampling system, and assorted valves, pressure and temperature sensors.

The CFV-CVS shall conform to the following requirements:

(1) Static pressure variations at the tailpipe(s) of the engine shall remain within ± 5 inches of water (1.2 kPa) of the static pressure variations measured during a dynamometer engine cycle with no connection to the tailpipe(s). Sampling systems capable of maintaining the static pressure to within ± 1.0 inch of water (0.25 kPa) will be used by the Administrator if a written request substantiates the need for this closer tolerance.)

(2) The temperature measuring system shall have an accuracy and precision of ± 2°F (1.1°C) and a response time of 0.100 seconds to 62.5 percent of a temperature change (as measured in hot silicone oil).

(3) The pressure measuring system shall have an accuracy and precision of ± 1.6 inches of water (0.4 kPa).

(4) The flow capacity of the CVS shall be large enough to virtually eliminate water condensation in the dilution system as well as in the gas sampling system.

(5) Sample collection bags for dilution air and exhaust samples shall be of sufficient size so as not to impede sample flow.

[§86.1310-83 Exhaust gas sampling system; diesel engines.

(a) General The exhaust gas sampling system described in this paragraph is designed to measure the true mass of both gaseous and particulate emissions in the exhaust of heavy-duty diesel engines. This system utilizes the CVS concept (described in §86.1309) of measuring mass emissions. The mass of gaseous emissions is determined from the sample concentration and total flow over the test period. The mass of particulate emissions is determined from a proportional mass sample collected on a filter and from the total flow over the test period. General requirements are as follows:

(1) This sampling system requires the use of a PDP-CVS or CFV-CVS with heat exchanger connected to a primary dilution tunnel. Figure N83-3 is a schematic drawing of the PDP system. Figure N83-4 is a schematic drawing of the CFV system.

(2) Diesel engines require a heated flame ionization detector (HFID) sample for hydrocarbon analysis. The HFID sample must be taken directly from the diluted exhaust stream through a heated probe in the dilution tunnel.

(3) Bag, HFID and particulate sampling capabilities as shown in Figure N83-3 (or Figure N83-4) are required to

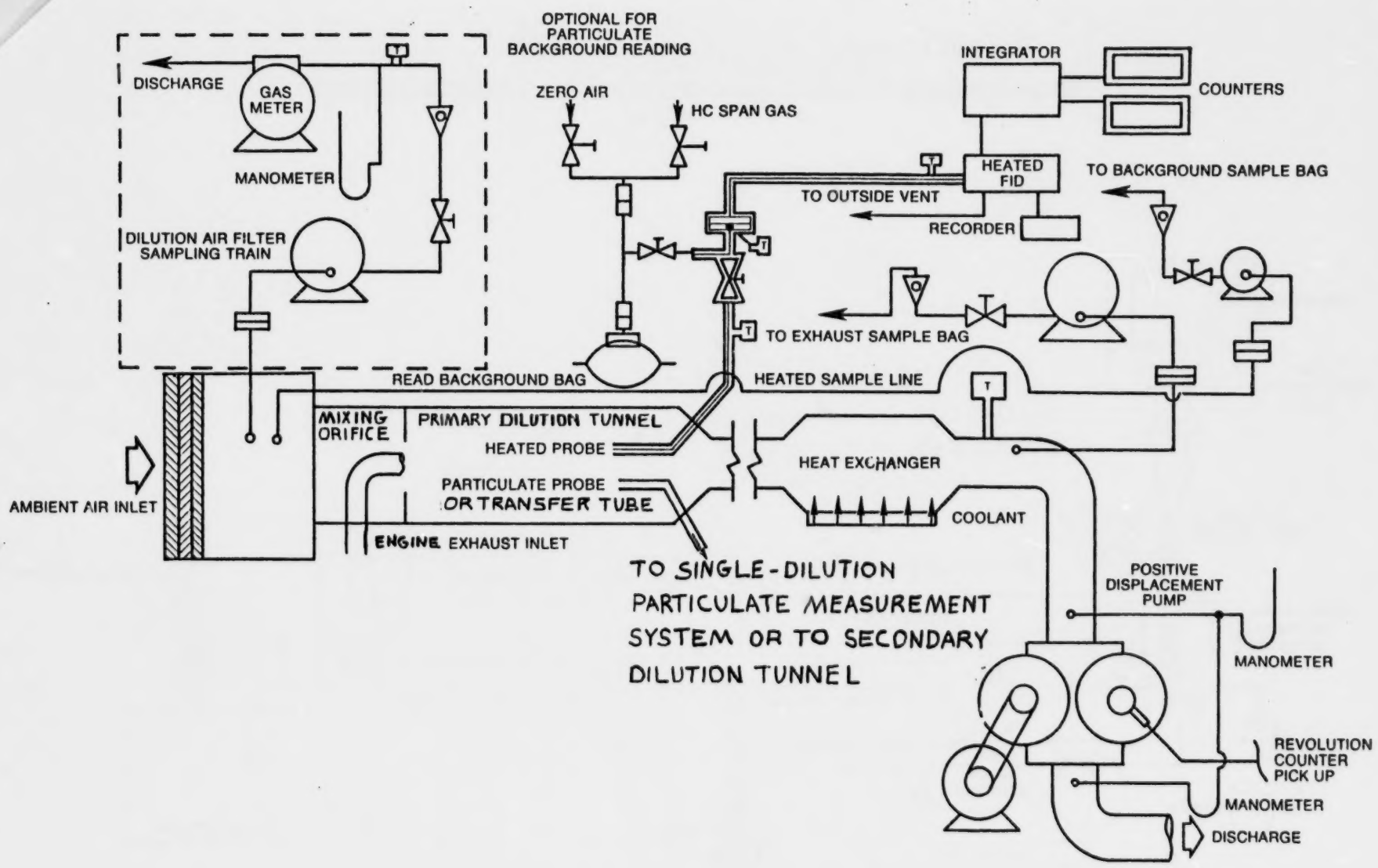

FIGURE N83-3
GASEOUS AND PARTICULATE EMISSIONS SAMPLING SYSTEM (PDP-CVS)
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N83-7 FOR SYMBOL LEGEND)

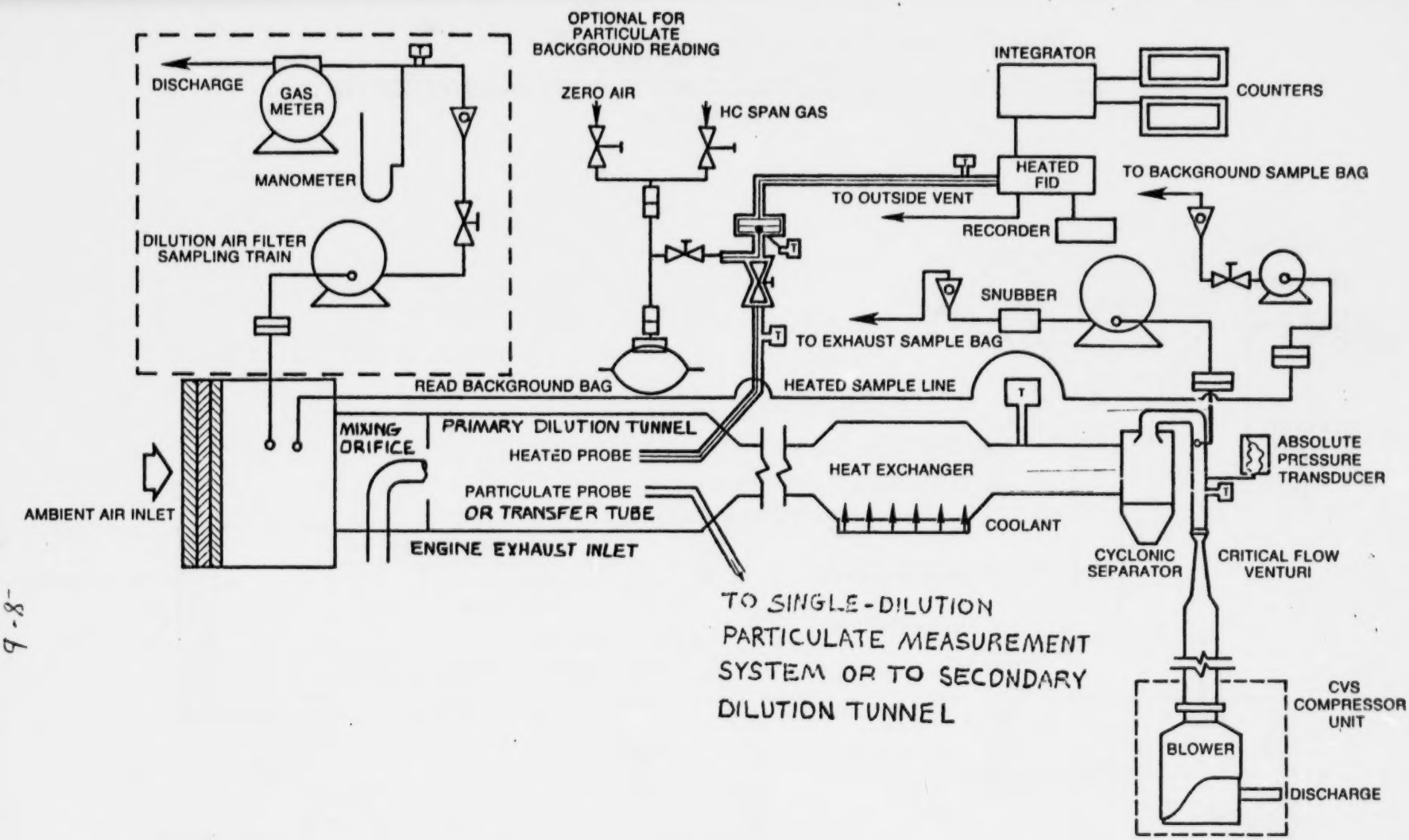

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FIGURE N83-4
GASEOUS AND PARTICULATE EMISSIONS SAMPLING SYSTEM (CFV-CVS)
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N83-7 FOR SYMBOL LEGEND)

provide both gaseous and particulate emissions sampling capabilities from a single system.

(4) Since various configurations can produce equivalent results, exact conformance with these drawings is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems.

(5) Other sampling systems may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(b) Component description. The components necessary for diesel exhaust sampling shall meet the following requirements:

(1) The PDP-CVS, shall conform to all of the requirements listed for the exhaust gas PDP-CVS (§86.1309 (b)), with the additional requirement that the CVS be sized to satisfy specific temperature limits for particulate and/or hydrocarbon measurements. This may be achieved by either of the following methods:

(A) Single-dilution method. A CVS of sufficient flow capacity to maintain a temperature of 125°F (51.7°C) or less

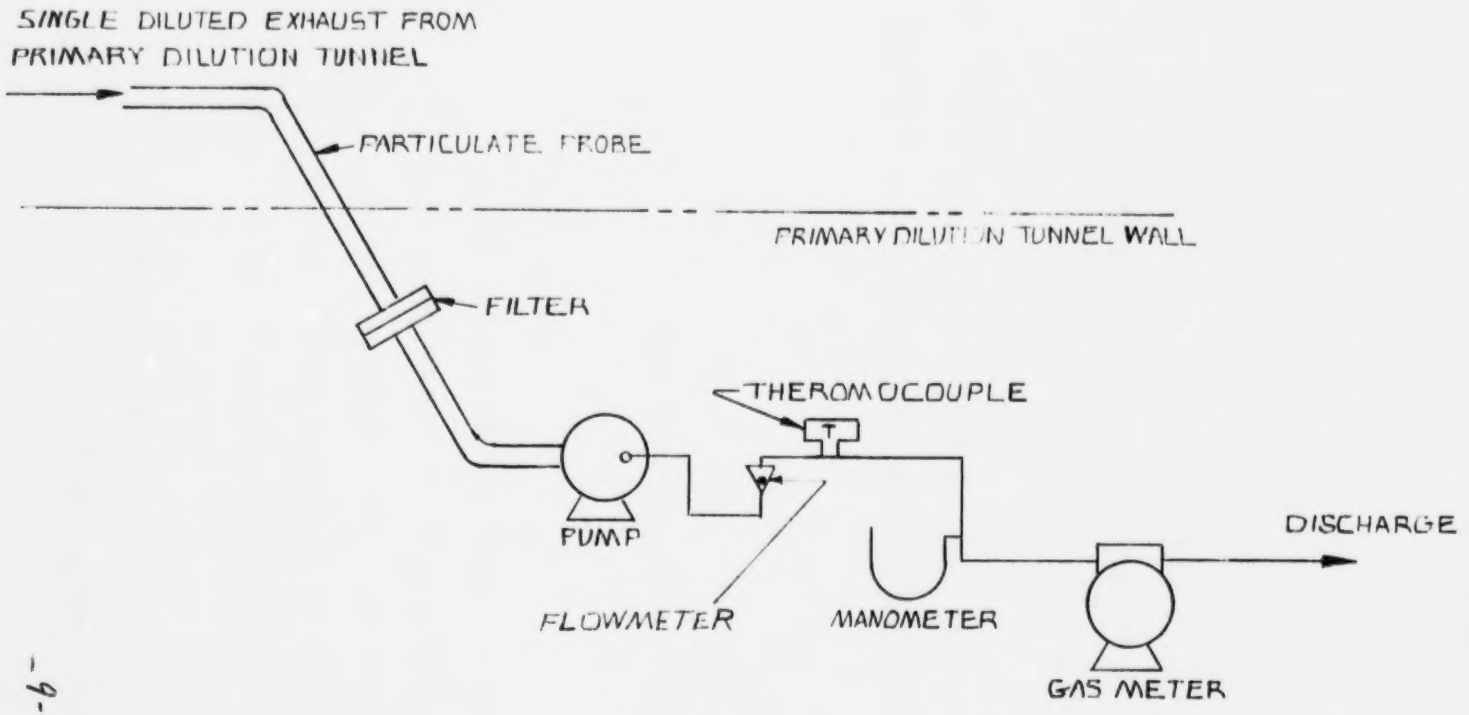

FIGURE N83-5
SINGLE DILUTION PARTICULATE MEASUREMENT SYSTEM
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N83-7 FOR SYMBOL LEGEND)

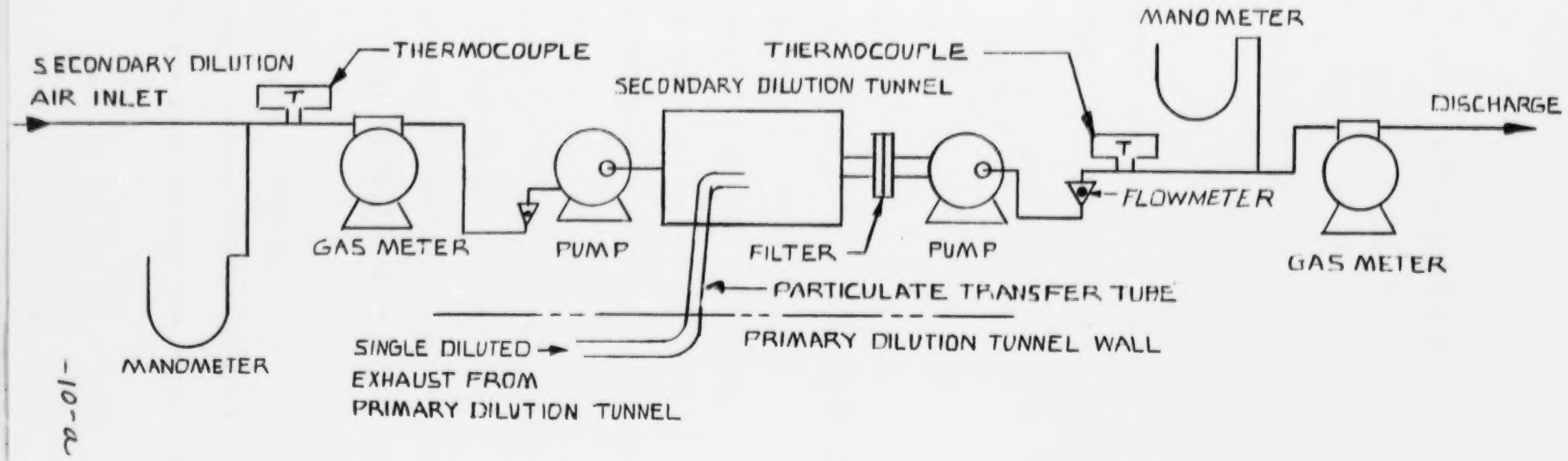

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FIGURE N83-6
DOUBLE DILUTION PARTICULATE MEASUREMENT SYSTEM
(FOR DIESEL ENGINES ONLY)
(SEE FIGURE N83-7 FOR SYMBOL LEGEND)

at the sampling zone may be used with the primary-dilution tunnel. Direct sampling of the particulate material may then take place (Figure N83-5).

(B) Double-dilution method. A smaller size CVS may be used with a smaller primary-dilution tunnel (i.e., smaller than the dilution tunnel or CVS described in §86.1310-83 (b)(1)(A)), and a secondary-dilution tunnel system (Figure N83-6). The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream in the primary-dilution tunnel at a temperature of 375°F (191°C) or less at the sampling zone. The secondary-dilution tunnel system must be designed to provide sufficient secondary dilution air to maintain the double diluted exhaust stream at a temperature of 125°F (51.7°C) or less immediately before the particulate filter.

(2) The CFV-CVS shall conform to all of the requirements listed for the exhaust gas CFV-CVS (§86.1309 (c)), along with the following three requirements:

(a) The CVS must be sized to satisfy specific temperature limits for particulate and/or hydrocarbon measurements. This may be achieved by either of the following methods:

(i) Single-dilution method. A CVS of sufficient flow

capacity to maintain a temperature of 125°F (51.7°C) or less at the sampling zone may be used with the primary-dilution tunnel. Direct sampling of the particulate material may then take place (Figure N83-5).

(ii) Double-dilution method. A smaller size CVS may be used with a smaller primary-dilution tunnel (i.e., smaller than the dilution tunnel or CVS described in §86.1310-83 (b)(2)(a)(i)), and a secondary-dilution tunnel system (Figure N83-6). The flow capacity of the CVS must be sufficient to maintain the diluted exhaust stream in the primary-dilution tunnel at a temperature of 375°F (191°C) or less at the sampling zone. The secondary dilution tunnel system must be designed to provide sufficient secondary dilution air to maintain the double diluted exhaust stream at a temperature of 125°F (51.7°C) or less immediately before the particulate filter.

(b) a heat exchanger is required (see Figure N83-4).

(c) the gas mixture temperature, measured at a point immediately ahead of the critical flow venturi, shall be within ± 20°F (11°C) of the designed operating temperature at the start of the test. The gas mixture temperature variation from its value at the start of the test shall be limited to ± 20°F (11°C) during the entire test. The temperature

measuring system shall have an accuracy and precision of ± 2°F (1.1°C).

(3) The transfer of heat from the engine exhaust gas shall be minimized between the point where it leaves the chassis exhaust system and the point where it enters the primary-dilution tunnel airstream. To accomplish this, a length (not more than 12 feet (3.66 m)) of insulated smooth stainless steel tubing from the muffler to the primary-dilution tunnel is required. This tubing shall have a maximum inside diameter of 5.0 inches (12.7 cm). Short sections (not to exceed 20 percent of tube length) of flexible tubing at connection points are allowed.

(4) The engine exhaust shall be directed downstream at the point where it is introduced into the primary-dilution tunnel.

(5) The primary-dilution air shall be at a temperature of 77 ± 9°F (25 ± 5°C).

(6) The primary-dilution tunnel shall be:

(i) sized to permit development of turbulent flow (Reynold's No. >4000) and complete mixing of the exhaust and dilution air between the mixing orifice; and

(ii) at least 18.0 inches (45.7 cm) in diameter;

(iii) constructed of electrically conductive material which does not react with the exhaust components.

(iv) grounded.

(7) The temperature of the diluted exhaust stream inside of the primary-dilution tunnel shall be sufficient to prevent water condensation.

(8) The particulate collection system must be configured in either of two basic ways, and depends upon the dilution method used. The single-dilution method utilizes a system that removes a single-diluted proportional sample from the primary tunnel, and then passes this sample through the collection filter (Figure N83-5).

The double-dilution method utilizes a collection system that transfers a single-diluted proportional sample from the primary tunnel to a secondary-dilution tunnel where the sample is further diluted, and then passes the complete double-diluted sample through the collection filter (Figure N83-6). In this system proportional sampling is achieved by; (1) introducing the secondary dilution air at a constant mass flow rate, and (2) removing the double-diluted sample at a constant

mass flow rate. The requirements for these two systems follow:

(a) Single-dilution method.

(i) The particulate sample probe shall be:

(A) installed facing upstream at a point where the dilution air and exhaust air are well mixed (i.e., on the primary tunnel certerline, approximatley 10 tunnel diameters downstream of the point where the exhaust enters the primary dilution tunnel).

(B) sufficiently distant (radially) from other sampling probes so as to be free from the influence of any wakes or eddies produced by the other probes.

(C) 1.27 cm (0.5 in.) minimum inside diameter.

(D) the distance from the sampling tip to the filter holder shall be at least 5 probe diameters (for filters located inside of the primary dilution tunnel), but not more than 40 inches (102 cm) for fiters located outside of the primary-dilution tunnel.

(E) free from sharp bends.

(ii) The flow rate through the particulate filter shall be at least the equivalent of 0.180 SCFM/in^2 (0.792 (L/min)/cm^2) of filter stain area, but not more than the equivalent of 0.600 SCFM/in^2 (2.638 (L/min)/cm^2) of filter stain area.

(iii) The particulate sample pump(s) shall be located sufficiently distant from the dilution tunnel so that the inlet gas temperature is maintained at a constant temperature ($\pm$ 5 °F(2.8°C)).

(iv) The gas meters shall be located sufficiently distant from the tunnel so that the inlet gas temperature remains constant ($\pm$ 5°F (2.8°C)).

(b) Double-dilution method.

(i) The particulate sample transfer tube shall be:

(A) configured and installed so that:

(1) the inlet faces upstream in the primary-dilution tunnel at a point where the primary-dilution air and exhaust are well mixed (i.e., on the primary tunnel centerline, approximately 10 tunnel diameters downstream of the point where the exhaust enters the primary-dilution tunnel).

(2) The exit faces downstream in the secondary-dilution tunnel.

(3) the single-diluted sample exits on the centerline of the secondary tunnel.

(4) constructed of electrically conductive material which does not react with the exhaust components.

(B) sufficiently distant (radially) from other sampling probes (in the primary-dilution tunnel) so as to be free from the influence of any wakes or eddies produced by the other probes.

(C) 0.5 inches (1.27 cm) minimum inside diameter.

(D) no longer than 35 inches (91.4 cm) from inlet plane to exit plane.

(E) free from sharp bends.

(ii) The secondary dilution air shall be at a temperature of 77 $\pm$ 9°F (25 $\pm$ 5°C).

(iii) The secondary-dilution tunnel shall be:

(A) 3.0 inches (7.62 cm) minimum inside diameter.

(B) of sufficient length so as to provide a residence time of two seconds for the double-diluted sample.

(C) constructed of electrically conductive material which does not react with the exhaust components.

(iv) Additional dilution air must be provided so as to maintain a maximum temperature of 125°F (51.7°C) immediately before the sample filter. This dilution air must be introduced at a constant mass flow rate in order to maintain proportional sampling. Determination of the mass of air entering the secondary dilution tunnel is required. Introduction and measurement can be achieved by either of the following methods:

(A) A PDP-type pump flowing filtered dilution air at a constant temperature (77 $\pm$ 9°F (25 $\pm$ 5°C)) and pressure (atmospheric is acceptable) along with a gas meter for mass determination. (See 86.1320-83 for calibration specifics.) The gas meter shall be located so that the inlet gas temperature remains constant (77 $\pm$ 9°F (25 $\pm$ 5°C)).

(B) A choked critical flow orifice flowing filtered dilution air. For mass determination a gas meter is accept-

able. (See §86.1320-83 for calibration specifics.) The gas meter shall be located so that the inlet gas temperature remains constant (77 ± 9°F (25 ± 5°C).

(v) The filter holder shall be located within 3.0 inches (7.5 cm) of the exit of the secondary-dilution tunnel.

(vi) The flow rate through the particulate filter shall be at least the equivalent of 0.180 SCFM/in^2 (0.792 (L/min)/cm^2)) of filter stain area, but not more than the equivalent of 0.600 SCFM/in^2 (2.638 (L/min/cm^2)) of filter face area.

(vi) The particulate sample pump shall be located sufficiently distant from the dilution tunnel so that the inlet gas temperature is maintained constant (± 5°F (2.8°C)).

(viii) The gas meter (if double-dilution this means the downstream meter) shall be located sufficiently distant from the tunnel (either primary or secondary) so that the inlet gas temperature remains constant (± 5°F (± 2.8°C)).

(9) The total hydrocarbon probe shall be:

(i) installed in the primary dilution tunnel facing upstream at a point where the dilution air and exhaust are well mixed (i.e., approximately 10 tunnel diameters downstream

of the point where the exhaust enters the dilution tunnel).

(ii) sufficiently distant (radially) from other probes so as to be free from the influence of any wakes or eddies produced by the other probes.

(iii) heated and insulated over the entire length to maintain a 375° ± 20°F (191° ± 11°C) wall temperature.

(iv) 0.25 in. (0.457 cm) minimum inside diameter.

(10) It is intended that the total hydrocarbon probe be free from cold spots (i.e., free from spots where the probe wall temperature is less than 355°F (180°C).

(11) The dilute exhaust gas flowing in the total hydrocarbon sample system shall be:

(i) at 375° ± 10°F (191° ± 6°C) immediately before the heated filter. This will be determined by a temperature sensor located immediately downstream of the filter. The sensor shall have an accuracy and precision of ± 2°F (1.1°C).

(ii) at 375° ± 10°F (191° ± 6°C) immediately before the HFID. This will be determined by a temperature sensor located at the exit of the heated sample line. The sensor

shall have an accuracy and precision of ± 2°F (1.1°C).

(12) It is intended that the dilute exhaust gas flowing in the total hydrocarbon sample system be between 365°F and 385°F (185°C and 197°C).

(c) Filters, particulate sampling.

(1) General. Filters must have diesel particulate collection efficiency of 98.0 percent or greater. The collection efficiency shall be determined by collecting particulate material on two different back-up filters while a the diesel engine is operated over a cold and a hot start Engine Dynamometer Test Run according to the procedure described in §86.1335 and §86.1337 with one exception: bag and HFID samples are not required. Requirements for a valid filter efficiency test are as follows:

(i) The efficiency test shall be performed on two randomly selected filters each followed by a back-up filter. One pair of filters is used to determine the efficiency during the cold start phase, and the other pair of filters is used to determine the efficienty during the hot start phase of an Engine Dynamometer Test Run.

(ii) The efficiency test shall be performed on each

different lot of filters used for diesel particulate measurement.

(iii) The components necessary for the filter efficiency test shall meet the requirements listed in §86.1310(b)(1) through (b)(7) with one exception: a back-up filter holder, located 7.5 to 10 cm (3 to 4 inches) downstream from the sample filter holder, is required.

(iv) The net weight of particulate material collected on either the cold start back-up filter or hot start back-up filter should not exceed 2.0 percent of the total net weight of particulate material collected on the repetitive cold start or hot start test filter plus the cold back-up filter. That is:

$$\frac{(\text{Mass Particulate})_{\text{Back-up filter}}}{(\text{Mass Particulate})_{\text{Test filter}} + (\text{Mass Particulate})_{\text{Back-up filter}}} \times 100\% \leq 2.0\%$$

(v) The net weight of particulate material collected on each back-up filter and each test filter shall be determined by the procedure outlined in §86.1339.

(2) If the efficiency of the filter is less than 98 percent, then a back-up filter in series with the first filter must be used during testing. The net weight of both filters will be combined when computing the emissions test results.

The back-up filter holder shall be located 3 to 4 inches (7.5 to 10 cm) downstream frm the first filter holder. All other components remain unchanged.

(3) The particulate filter must have a minimum 70 mm diameter (60 mm stain diameter). Larger diameter filters are also acceptable. (Larger diameter filters may be desirable in order to reduce the pressure drop across the filter when testing vehicles which produce large amounts of particulate.)

(4) The recommended loading on the 70 mm filter is 5.3 to 18.4 milligrams. Equivalent loadings (i.e., mass/area) are recommended for larger filter. For equivalency calculations assume the 70 mm loading has a 60 mm stain diameter.

(5) Fluorocarbon coated glass fiber filters are required for particulate collection.]

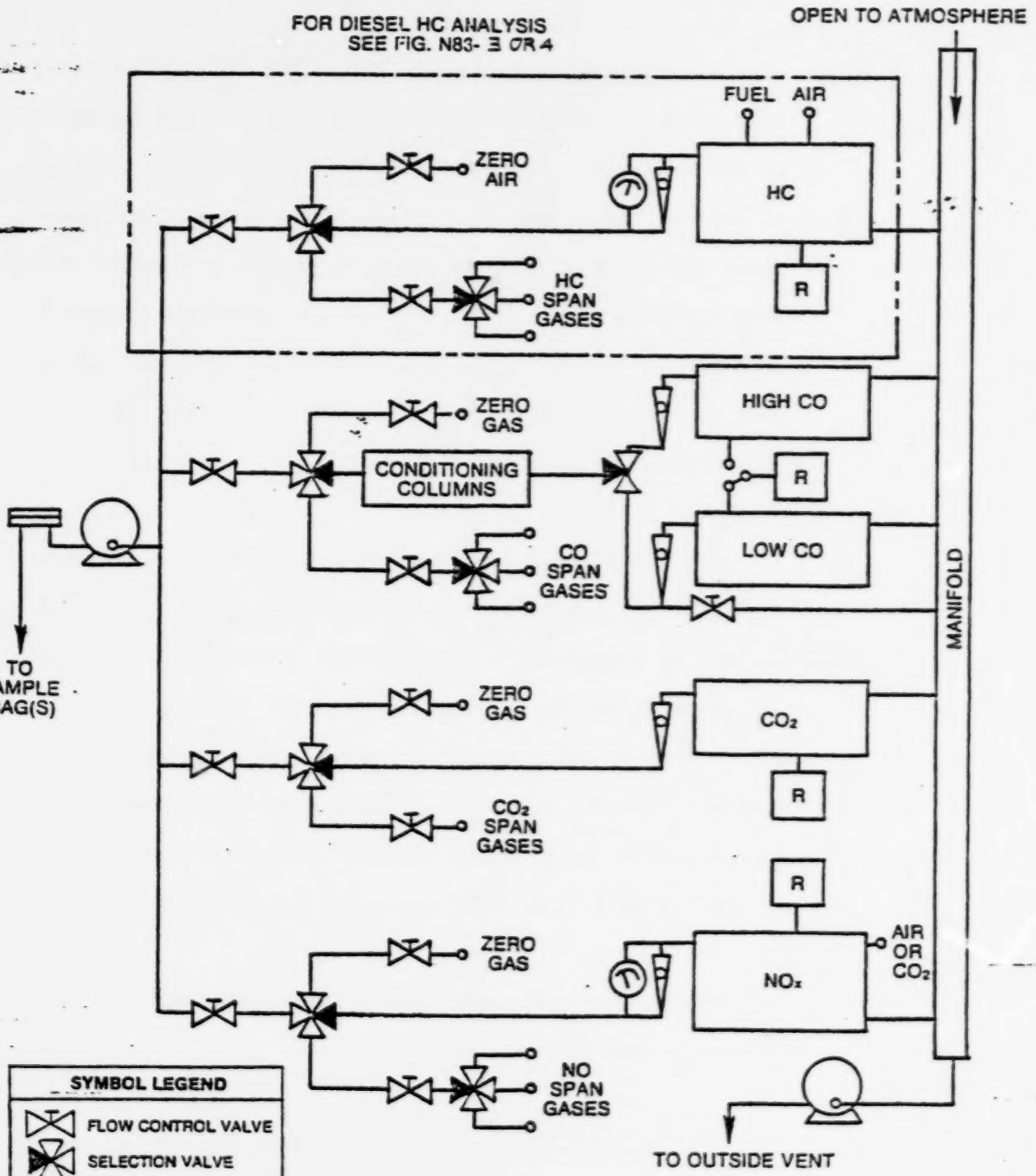

FIGURE N83-7 EXHAUST GAS ANALYTICAL SYSTEM

§86.1311-83 Exhaust gas analytical system.

(a) Schematic drawings. Figure [N83-7] is a schematic drawing of the exhaust gas analytical system. The schematic of the hydrocarbon analysis train for diesel engines is shown as part of Figure [N83-3 or N83-4]. Since various configurations can produce accurate results, exact conformance with either drawing is not required. Additional components such as instruments, valves, solenoids, pumps, and switches may be used to provide additional information and coordinate the functions of the component systems.

(b) Major component description. The analytical system, Figure [N83-7], consists of a flame ionization detector (FID) for the determination of hydrocarbons, nondispersive infrared analyzers (NDIR) for the determination of carbon monoxide and carbon dioxide and a chemiluminescence analyzer (CL) for the determination of oxides of nitrogen. A heated flame ionization detector (HFID) is used for the continuous determination of hydrocarbons from diesel engines, Figure [N83-3 or N83-4].

The exhaust gas analytical system shall conform to the following requirements:

(1) The CL requires that the nitrogen dioxide present in the sample be converted to nitric oxide before analysis.

Other types of analyzers may be used if shown to yield equivalent results and if approved in advance by the Administrator.

(2) The carbon monoxide (NDIR) analyzer may require a sample conditioning column containing $CaSO_4$, or indicating silica gel to remove water vapor and containing ascarite to remove carbon dioxide from the CO analysis stream.

(i) If CO instruments which are essentially free of CO_2 and water vapor interference are used, the use of the conditioning column may be deleted, see §86.1322 and §86.1344.

(ii) A CO instrument will be considered to be essentially free of CO_2 and water vapor interference if its response to a mixture of 3 percent CO_2 in N_2 which has been bubbled through water at room temperature produces an equivalent CO response, as measured on the most sensitive CO range, which is less than 1 percent of full scale CO concentration on ranges above 300 ppm full scale or less than 3 ppm on ranges below 300 ppm full scale, see §86.1322.

(3) For diesel engines a continuous hydrocarbon sample shall be measured using a heated analyzer train as shown in Figure [N83-3 or N83-4]. The train shall include a heated continous sampling line, a heated particulate filter, and a heated hydrocarbon instrument (HFID) complete with heated

pump, filter and flow control system.

(i) The response time of this instrument shall be less than 1.5 seconds for 90 percent of full-scale response.

(ii) Sample transport time from sampling point to inlet of instrument shall be less than 4 seconds.

(iii) The sample line and filter shall be heated to maintain a sample gas temperature of 375 $\pm$ 10°F (191 $\pm$ 6°C) before the filter and before the HFID.

(c) Other analyzers and equipment. Other types of analyzers and equipment may be used if shown to yield equivalent results and if approved in advance by the Administrator.

§86.1312-81 Weighing chamber (or room) and microgram balance specifications.

(a) Ambient conditions.

(1) Temperature. The temperature of the chamber in which the particulate filters are conditioned and weighed shall be maintained to within ± 10°F (6°C) of a set point between 68°F (20°C) and 86°F (30°C) during all filter conditioning and filter weighing.

(2) Humidity. The relative humidity of the chamber in which the particulate filters are conditioned and weighed shall be maintained to within ± 10 percent of a set point between 30 and 70 percent during all filter conditioning and filter weighing.

(3) The environment shall be free from any ambient contaminates (such as dust) that would settle on the particulate filters during their stabilization. It is required that two reference filters remain in the weighing room at all times, and that these filters be weighed at the beginning and end of each conditioning period. If the weight of either or both of these two reference filters changes by more than ± 1.0 percent of the nominal filter loading (5.3-18 milligrams) during the conditioning period, then all filters in the

process of being stabilized should be discarded, and any tests repeated.

(b) Microgram balance specifications.

The microgram balance used to determine the weights of all filters shall have a precision (standard deviation) and a readability (micrometer) of one microgram.]

[§86.1320-83 Gas meter calibration, particulate measurement.

Sampling for particulate emissions requires the use of gas meters to determine flow through the particulate filters. These meters shall receive initial and periodic calibrations as follows:

(a) Install a standard air flow measurement instrument (such as laminar flow element) upstream of the gas meter. This standard instrument shall measure air flow at standard conditions. Standard conditions are defined as 68°F (20°C) and 29.92 inches of mercury (101.3 kPa). A critical flow orifice, a bellmouth nozzle, or a laminar flow element is recommended as the standard instrument.

(b) Flow air through the calibration system at the sample flow rate used for particulate testing and at the backpressure which occurs during the sample test.

(c) When the temperature and pressure in the system have stabilized, measure the gas meter indicated volume over a time period of at least 5 minutes and until a flow volume of at least $\pm$ 1 percent accuracy can be determined by the standard instrument. Record the stabilized air temperature and pressure upstream of the gas meter and as required for the standard instrument.

(d) Calculate air flow at standard conditions as measured by both the standard instrument and the gas meter.

(e) Repeat the procedures of paragraphs (b) through (d) above using flow rates which are 10 percent above the nominal sampling flow rate and 10 percent below the nominal sampling flow rate.

(f) If the air flow at standard conditions measured by the gas meter differs by more than ± 1 percent from the standard measurement at any of the three measured flow rates, than a correction shall be made by either of the following two methods:

(1) Mechanically adjust the gas meter so that it agrees within 1 percent of the standard measurement at the three specified flow rates, or

(2) Develop a continuous best fit calibration curve for the gas meter (as a function of the standard instrument flow measurement) from the three calibration points that represents the data to within 1 percent at all points to determine corrected flow.

(g) Other systems.

A bell prover may be used to calibrate the gas meter if the procedure outlined in ANSI B109.1-1973 is used. Prior approval by the Administrator is not required to use the bell prover.]

§86.1321-83 Hydrocarbon analyzer calibration.

The FID hydrocarbon analyzer shall receive the following initial and periodic calibration. The HFID shall be operated at a temperature of 375 ± 10°F (191° ± 6°F).

(a) Initial and periodic optimization of detector response. Prior to its introduction into service and at least annually thereafter the FID hydrocarbon analyzer shall be adjusted for optimum hydrocarbon response. Alternate methods yielding equivalent results may be used, if approved in advance by the Administrator.

(1) Follow the manufacturer's instructions or good engineering practice for instrument start-up and basic operating adjustment using the appropriate fuel (see §86.1314) and zero-grade air.

(2) Optimize on the most common operating range. [For diesel engines, optimize the HFID on the required operating range. (See §86.1338-83 for determining the required operating range.)] Introduce into the analyzer, a propane in air mixture with a propane concentration equal to approximately 90% of this operating range.

(3) Select an operating fuel flow rate that will give

near maximum response and least variation in response with minor fuel flow variations.

(4) To determine the optimum air flow, use the fuel flow setting determined above and vary air flow.

(5) After the optimum flow rates have been determined, they are recorded for future reference.

(b) Initial and periodic calibration. Prior to its introduction into service and monthly thereafter the FID hydrocarbon analyzer shall be calibrated on all normally used [(or required)] instrument ranges. Use the same flow rate as when analyzing samples.

(1) Adjust analyzer to optimize performance.

(2) Zero the hydrocarbon anlyzer with zero-grade air.

(3) Calibrate on each used [(or required in the case of diesel engines)] operating range with propane in air calibration gases having nominal concentrations of 15, 30, 45, 60, 75 and 90 percent of that range. For each range calibrated, if the deviation from a least-squares best-fit straight line is 2% or less of the value at each data point, concentration values may be calculated by use of a single calibration factor

for that range. If the deviation exceeds 2% at any point, the best-fit non-linear equation which represents the data to within 2% of each test point shall be used to determine concentration.

§86.1327-83 Engine dynamometer test procedures; overview.

(a) The engine dynamometer test procedure is designed to determine the brake-specific emission of hydrocarbons, carbon monoxide, oxides of nitrogen, [and particulate (diesels only)]. The test procedure consists of a "cold" start test after a minimum 12-hour and a maximum 36-hour soak as described in §86.1332. A "hot" start test follows the "cold" start test after a hot soak of 20 minutes. The idle test of subpart P may be run after the "hot start" test. The exhaust emissions are diluted with ambient air and a continuous proportional sample is collected for analysis during both the cold and hot start tests. [For gasoline-fueled engines] the composite samples collected in bags are analyzed for hydrocarbons carbon monoxide, carbon dioxide, and oxides of nitrogen. [For diesel engines, the composite samples in bags are analyzed for carbon monoxide, carbon dioxide, and oxides of nitrogen. Diesel hydrocarbons are continuously analyzed. Diesel particulates are collected on fluorocarbon coated glass fiber filters. For both types of engines parallel samples of the dilution air is similarly analyzed for hydrocarbon, carbon monoxide, carbon dioxide, and oxides of nitrogen. Dilution air is prefiltered.]

(b) Engine torque and rpm shall be recorded continuously during both the cold and hot start tests. Data points shall

be recorded at least once every second.

(c) Using the torque and rpm feedback signals the brake horsepower is integrated with respect to time for the cold and hot cycles. This produces a brake horsepower-hour value that enables the brake-specific emissions to be determined (see §86.1344, Calculations; exhaust emissions).

(d)(1) When an engine is tested for exhaust emissions or is operated for service accumulation on an engine dynamometer, the complete engine shall be tested, with all emission control devices installed and functioning.

(2) Evaporative emission controls need not be connected if data are provided to show that normal operating conditions are maintained in the engine induction system.

(3) On air cooled engines, the fan shall be installed.

(4) Additional accessories (e.g., oil cooler, alternators, air compressors, etc.) may be installed with advance approval by the Administrator.

(5) The engine must be equipped with a production type starter.

§86.1332-83 Pre-test procedures.

(a) Mount test engine on the engine dynamometer.

(b) Determine maximum engine speed.

(1) Gasoline-fueled.

(i) For ungoverned engines the maximum engine speed shall be the manufacturer's recommended maximum safe operating speed.

(ii) For governed engines the maximum engine speed shall be the speed at which there is at least a 50 percent drop-off in torque.

(2) Diesel fueled. The maximum engine speed shall be the manufacturer's rated speed.

(c) Determine minimum engine speed.

(1) Gasoline-fueled. The minimum engine speed is calculated from the following equation:

minimum speed = (curb idle - 200 rpm)
or 400 rpm, whichever is greater

(2) Diesel fueled. The minimum engine speed is calculated from the following equation:

minimum speed = 0.6(manufacturer's rated speed)

(d) Determine maximum torque curve.

(1) Gasoline-fueled.

(i) Start the engine and operate at zero load in accordance with the manufacturer's start-up and warm-up procedures for 1 minute ± 30 seconds.

(ii) Operate the engine at a torque equivalent to 10 ± 3 percent of the most recent determination of maximum torque for 4 minutes ± 30 seconds at 2000 rpm.

(iii) Operate the engine at a torque equivalent to 55 ± 5 percent of the most recent determination of maximum torque for 35 minutes ± 1 minute at 2000 rpm.

(iv) Operate the engine at idle.

(v) Operate the throttle fully.

(vi) While still maintaining wide-open throttle and full-load obtain minimum engine speed. Maintain minimum engine speed for 15 seconds.

(vii) Record the average torque during the last 5 seconds.

(viii) In 100 rpm increments determine the maximum torque curve from minimum speed to maximum speed. Hold each test point for 15 seconds and record the average torque over the last 5 seconds.

(2) Diesel fueled.

(i) Start the engine and operate at idle for 2 to 3 minutes.

(ii) Operate the engine at approximately 50 percent power at the peak torque speed for 5 to 7 minutes.

(iii) Operate the engine at rated speed and maximum horsepower for 25 to 30 minutes.

(iv) Option. It is permitted to precondition the engine at rated speed and maximum horsepower until the oil and water temperatures are stabilized. The temperatures are stabilized if they are maintained within 2 percent of point for 2 minutes. The engine must be operated a minimum of 10 minutes for this option. This optional procedure may be substituted for step (iii).

[(v) Operate engine at rated speed, rated torque. Adjust inlet depression as required (see §86.1308) and observe exhaust back pressure.]

[(vi)] Unload the engine and measure the curb idle speed.

[(vii)] Operate the engine at wide-open throttle and minimum engine speed. Maintain minimum engine speed for 30 seconds.

[(viii)] Record the average torque over the last 5 seconds.

[(ix)] In 200 rpm increments determine the maximum torque

curve from minimum speed to the maximum speed (rated speed). Hold each test point for 30 seconds and record the average torque over the last 5 seconds.

[(x)] Unload the engine, maintain wide-open throttle, and measure the high idle speed.

(e) Mapping curve generation.

(1) Gasoline-fueled.

(i) Fit all data points recorded under (d)(1) of this section with a cubic spline curve generation technique. The resulting curve is the mapping curve and will be used to convert the normalized torque values in the engine cycles (see Appendix I f and g) to actual torque values.

(2) Diesel fueled.

(i) Calculate the torque at curb idle using the equation below. Assume a BMEP of 90 PSI.

$$T = \frac{(BMEP)(D)(5252)}{(12)(33000)x}$$

Where:

BMEP = brake mean effective pressure, psi;

T = engine torque, lb.-ft.;

D = total piston displacement, cubic inches:

x = number of revolutions required for each power stroke delivered per cylinder -- 2 for a four-stroke cycle engine and 1 for a two-stroke cycle engine.

(ii) Fit all the torque values recorded under (d)(2) of this section with a cubic spline curve generation technique.

(iii) Draw a straight line from the maximum torque at curb idle (as calculated in (e)(2)(ii) of this section) to the maximum torque at minimum speed (as calculated from the cubic spline curve generated in (e)(2)(ii) of this section).

(iv) Draw a straight line between the maximum torque at rated speed (curve value) and zero torque at high idle rpm.

(v) The complete mapping curve is shown in Figure N83-[14].

The resulting mapping curve is used to convert the normalized torque values in the engine cycles (see Appendix I) to actual torque values.

(f) Engine preparation.

(i) Before the cold soak, practice cycle runs may be performed, but emissions may not be measured. A maximum of 8 hours of practice is allowed.

(ii) After any practice runs, turn the engine off and

allow to cold soak at 60° to 80°F for a minimum of 12 hours and a maximum of 36 hours.

§86.1336-83 Engine starting and restarting.

(a) Gasoline-fueled engines.

(1) The engine shall be started with a production engine starting-motor according to the manufacturer's recommended starting procedures in the owner's manual. The 24 ± 1 second free idle period shall begin when the engine starts.

(2) Choke operation:

(i) Engines equipped with automatic chokes shall be operated according to the manufacturer's operating instructions in the owner's manual, including choke setting and "kick-down" from cold fast idle.

(ii) Engines equipped with manual chokes shall be operated according to the manufacturer's operating instructions in the owner's manual.

(3) The operator may use the choke, throttle, etc. where necessary to keep the engine running.

(4) If the manufacturer's operating instructions in the owner's manual do not specify a warm engine starting procedure, the engine (automatic- and manual-choke engines) shall be

started by depressing the throttle about half way and cranking the engine until it starts.

(b) Diesel engines. The engine shall be started with a production engine starting-motor according to the manufacturer's recommended starting procedures in the owner's manual. The 24 ± 1 second free idle period shall begin when the engine starts.

(c)(1) If the engine does not start after 15 seconds of cranking, cranking shall cease and the reason for failure to start shall be determined. The gas flow measuring device (or revolution counter) on the constant volume sampler, the hydrocarbon integrator [and particulate sample pump(s)] when testing diesel vehicles, see §86.1337, Engine dynamometer test run) shall be turned off and the sample selector valves placed in the "standby" position during this diagnostic period. In addition, either the CVS should be turned off or the exhaust tube disconnected from the tailpipe during the diagnostic period. If failure to start is an operational error, the engine shall be rescheduled for testing from a cold start.

(2) If a failure to start occurs during the cold portion of the test and is caused by an engine malfunction, corrective action of less than 30 minutes duration may be taken (according to §86.083-25), and the test continued. The sampling

system shall be reactivated at the same time cranking begins. When the engine starts, the timing sequence shall begin. If failure to start is caused by engine malfunction and the engine cannot be started, the test shall be voided and corrective action may be taken according to §86.083-25. The reasons for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

(3) If a failure to start occurs during the hot start portion of the test and is caused by engine malfunction, the engine must be started within one minute of key on. The sampling system shall be reactivated at the same time cranking begins. When the engine starts, the transient engine cycle timing sequence shall begin. If the engine cannot be started within one minute of key on, the test shall be voided, corrective action taken, (according to §86.083-25), and the engine rescheduled for testing. The reason for the malfunction (if determined) and the corrective action taken shall be reported to the Administrator.

(d) If the engine "false starts", the operator shall repeat the recommended starting procedure (such as resetting the choke, etc.).

(e) Engine stalling.

(1) If the engine stalls during the initial idle period of either the cold or hot start test, the engine shall be restarted immediately using the appropriate cold or hot starting procedure and the test continued. If the engine cannot be started before the first non-idle record of the cycle, the test shall be voided.

(2) If the engine stalls anywhere in the cycle, except in the initial idle period, the test shall be voided.

§86.1337-83 Engine dynamometer test run.

(a) The following steps shall be taken for each test:

(1) Prepare the engine and dynamometer for the cold start test.

(2) With the sample selector valves in the "standby" position, connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(3) Start the CVS (if not already on), the sample pumps [(except the diesel particulate sample pumps(s), if applicable)], the temperature recorder, the engine cooling fan(s) and the heated hydrocarbon analysis recorder (diesel only). (The heat exchanger of the constant volume sampler, if used, diesel hydrocarbon analyzer continuous sample line and filter (if applicable) shall be preheated to their respective operating temperatures before the test begins.)

(4) Adjust the sample flow rates to the desired flow rate and set the gas flow measuring devices to zero.

[(i) For gaseous samples the minimum flow rate is 0.17 SCFM (4.81 L/min).]

[(ii) For particulate samples the filter flow rate must be at least 0.180 SCFM/in^2 (0.792 L/min/cm^2), but not greater than 0.600 SCFM/in^2 (2.638 L/min/cm^2). Use the effective filter stain area in determining the flow rate.]

NOTE: The CFV-CVS sample flowrate for gaseous emissions is fixed by the venturi design.

(5) Attach the CVS flexible exhaust tube to engine tailpipe(s).

[(6) Carefully install a clean particulate sample filter into the filter holder for diesel tests. The filter must be handled only with forceps or tongs. Rough or abrasive filter handling will result in erroneous weight determination.]

(7) Follow the manufacturer's choke and throttle instructions for cold starting. Simultaneously start the engine and begin exhaust and dilution air sampling. For diesel engines, turn on the hydrocarbon analyzer system integrator, mark the recorder chart, [and turn on the particulate sample pump(s).]

(8) As soon as it is determined that the engine is started, start a "free idle" timer.

(9) Allow the engine to idle freely with no-load for 24 ± 1 seconds.

(10) Begin the transient engine cycles such that the first non-idle record of the cycle occurs at 25 ± 1 seconds. The free idle time is included in the 25 ± 1 seconds.

[NOTE. During diesel testing, adjust the sample pump(s) so that the flow rate through the particulate sample probe or transfer tube is maintained at a constant value within ± 5 percent of the set flow rate. Record the average temperature and pressure at the gas meter(s) inlet. If the set flow rate cannot be maintained because of high particulate loading on the filter, the test shall be terminated. The test shall be rerun using lower flow rate and/or a larger diameter filter.]

(11) On the last record of the cycle cease sampling, immediately turn the engine off, and start a hot soak timer. [For diesel engines simultaneously turn off gas flow measuring device(s) and the diesel hydrocarbon integrator, mark the hydrocarbon recorder chart, and turn off the particulate sample pump(s).]

(12) Immediately after the engine is turned off, turn off the engine cooling fan(s) if used, and the CVS blower. As soon as possible transfer the "cold start cycle" exhaust and

dilution air samples to the analytical system and process the samples according to §86.1340 obtaining a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test. [For diesel engines carefully remove the particulate sample filter from its holder and place it in a petri dish, and cover.]

(13) Allow the engine to soak for 20 ± 1 minutes.

(14) Prepare the engine and dynamometer for the hot start test.

(15) With the sample selector valves in the "standby" position, connect evacuated sample collection bags to the dilute exhaust and dilution air sample collection systems.

(16) Start the CVS (if not already on), the sample pumps [(except the diesel particulate sample pump(s) if applicable)], the temperature recorder, the engine cooling fan and the heated hydrocarbon analysis recorder (diesel only). (The heat exchanger of the constant volume sampler, if used, diesel hydrocarbon analyzer continuous sample line and filter (if applicable) shall be preheated to their respective operating temperatures before the test begins.)

(17) Adjust the sample flow rates to the desired flow

rate and set the gas flow measuring devices to zero.

[(i) For gaseous samples the minimum flow rate is 0.17 SCFM (4.81 L/min).]

[(ii) For particulate samples the filter flow rate must be at least 0.180 SCFM/in^2 (0.792 L/min/cm^2), but not greater than 0.600 SCFM/in^2 (2.638 L/min/cm^2)/ Use the effective filter stain area in determining the flow rate.]

NOTE: The CFV-CVS sample flowrate for gaseous emissions is fixed by the venturi design.

[(18) Carefully install a clean particulate filter into the filter holder for diesel tests. The filter must be handled only with forceps or tongs. Rough or abrasive filter handling will result in erroneous weight determination.]

(19) Follow the manufacturer's choke and throttle instruction for hot starting. Simultaneously start the engine and begin exhaust and dilution air sampling. [For diesel engines, turn on the hydrocarbon analyzer system integrator, mark the recorder chart, and turn on the particulate sample pump(s).]

(20) As soon as it is determined that the engine is

started, start a "free idle" timer.

(21) Allow the engine to idle freely with no-load for 24 ± 1 seconds.

(22) Begin the transient engine cycle such that the first non-idle record of the cycle occurs at 25 ± 1 seconds. The free idle is included in the 25 ± 1 seconds.

(23) On the last record of the cycle cease sampling. [For diesel engines, simultaneously turn off gas flow measuring device(s) and the diesel hydrocarbon integrator, mark the hydrocarbon recorder chart, and turn off the particulate sample pump(s).]

(24) As soon as possible transfer the "hot start cycle" exhaust and dilution air samples to the analytical system and process the samples according to §86.1340 obtaining a stabilized reading of the exhaust sample on all analyzers within 20 minutes of the end of the sample collection phase of the test.

[(25) For diesel engines, carefully remove the particulate sample filter from its holder and place in a clean petri dish and cover as soon as possible. Within one hour after the end of the hot start phase of the test, transfer the two particulate filters to the weighing chamber for post-test conditioning.]

(26) Disconnect the exhaust tube from the engine tailpipe(s).

(27) The CVS may be turned off, if desired.

[§86.1338-83 Hydrocarbon measurement accuracy; diesel engines.

(a) The HFID analyzer must be operated between 15 percent and 100 percent of full-scale chart deflection during the measurement of the hydrocarbon emissions for each mode. The exceptions to the lower limit of this operating rule are:

(1) The analyzer's response may be less than 15 percent of full scale if the full-scale value is 155 ppmC or less.

(2) The HFID analyzer's response may be less than 15 percent of full scale if the emissions from the engine are erratic and the average chart-deflection value is greater than 15 percent of full scale.

(3) The HFID analyzer's response may be less than 15 percent of full scale if the contribution of all modes read below the 15 percent level is less than 10 percent by mass of the final test results.]

[§86.1339-83 Diesel particulate filter handling and weighing.

(a) At least 8 hours, but not more than 56 hours before the test, place each filter in an open, but protected, petri dish and place in the weighing chamber which meets the humidity and temperature specifications of §86.1312.

(b) At the end of the 8 to 56 hour stabilization period, weigh the filter on a balance having a precision of one microgram. Record this weight. This reading is the tare weight.

(c) The filter shall then be stored in a covered petri dish which shall remain in the weighing chamber until needed for testing.

(d) If the filter is not used within one hour of its removal from the weighing chamber, it shall be re-weighed.

(e) After the test, and after the sample filter is returned to the weighing room, condition it for at least 8 hours but not more than 56 hours. Then weigh a second time. This latter reading is the gross weight of the filter. Record this weight.

(f) The net weight (M_{P_f}) is the gross weight minus the

tare weight.

NOTE. - Should the sample on the filter contact the petri dish or any other surface, the test is void and must be re-run.]

§86.1340-83 Exhaust sample analysis; gaseous emissions.

The following sequence of operations shall be performed in conjunction with each series of measurements:

(a) Zero the analyzers and obtain a stable zero reading. Recheck after tests.

(b) Introduce span gases and set instrument gains. In order to avoid corrections, span and calibrate at the same flow rates used to analyze the test sample. Span gases shall have concentrations equal to 75 to 100 percent of full scale. If gain has shifted significantly on the analyzers, check the calibrations. Show actual concentrations on chart.

(c) Check zeros; repeat the procedure in paragraphs (a) and (b) of this section if required.

(d) Check flow rates and pressures.

(e) Measure HC, CO, CO_2 and NOx concentrations of samples.

(f) For diesel engines, continuously record (integrate electronically if desired) dilute hydrocarbon emission levels during test. Background samples are collected in sample bags

and analyzed as above.

[NOTE: For quality control check, compare an analysis of a background bag to a continuous analysis of background sampled through total hydrocarbon probe. For best results, the difference should be less than 1 percent of the average (time integrated) dilute hydrocarbon emission level during the test.]

(g) Check zero and span point. If difference is greater than 2% of full scale, repeat the procedure in paragraphs (a) through (f).

§86.1342-83 Records required.

The following information, as applicable, shall be recorded for each test:

(a) Engine description and specification. A copy of the information specified in this paragraph must accompany each engine sent to the Administrator for compliance testing. The manufacturer need not record the information specified in this paragraph for each test if the information, with the exception of subparagraph (3) is included in the manufacturer's Part I.

(1) Engine-system combination.

(2) Engine identification numbers.

(3) Number of hours of operation accumulated on engine.

(4) Manufacturer's rated maximum horsepower and torque.

(5) Manufacturer's rated maximum horsepower and torque speeds.

(6) Engine displacement.

(7) Governed speed.

(8) Maximum safe engine speed (ungoverned engines).

(9) Manufacturer's start-up procedure.

(10) Curb-idle rpm.

(11) [Inlet depression.

(i) Manufacturer's recommended inlet depression limit.

(ii) Typical in-use inlet depression level.

(12) Exhaust system.

(i) Diesel engines.

(A) Header pipe inside diameter.

(B) Tailpipe inside diameter.

(C) Minimum distance in-use between the exhaust manifold flange and the exit of the chassis exhaust system.

(D) Manufacturer's recommended maximum exhaust back pressure limit for the engine.

(E) Typical back pressure as determined by the maximum back pressure application of the engine.

(F) Minimum back pressure required to meet applicable

noise regulations.

(ii) Gasoline-fueled engines. Typical in-use back pressure in vehicle exhaust system.]

(b) Test data; general. This information may be recorded at any time between 4 hours prior to the test and 4 hours after the test.

(1) Engine-system combination.

(2) Engine identification number.

(3) Instrument operator(s).

(4) Engine operator(s).

(5) Number of hours of operation accumulated on the engine prior to beginning the test sequence (Figure N83-[13]).

(6) Fuel identification, including H/C ratio.

(7) Date of most recent analytical assembly calibration.

(8) All pertinent instrument information such as tuning, gain, serial numbers, detector number, calibration curve

numbers, etc. As long as this information is traceable, it may be summarized by system number or analyzer identification numbers.

(c) Test data; pre-test.

(1) Date and time of day.

(2) Test number.

(3) Engine intake air temperature.

(4) Barometric pressure.

(5) Engine intake humidity.

(6) Maximum torque curve as determined in §86.1332.

(7) Measured maximum horsepower and torque speeds.

(8) Measured maximum horsepower and torque.

(9) Maximum engine speed.

(10) Minimum engine speed.

(11) High idle engine speed (diesel engines only).

(12) Calculated torque at curb-idle (diesel engines only).

(13) Fuel consumption at maximum power and torque (diesel engines only).

(14) Curb-idle fuel flow rate.

[(15) Inlet depression.]

[(16) Exhaust back pressure.]

(d) Test data.

(1) Total number of hours of operation accumulated on the engine prior to starting emission test.

(2) Cold soak time interval.

(3) Recorder charts: Identify zero, span, exhaust gas, and dilution air sample traces.

(4) Test cell barometric pressure.

NOTE: A central laboratory barometer may be used: Provided, That individual test cell barometric pressure are shown to be within ±0.1 percent of the barometric pressure at the central barometer location.

(5) Engine intake air temperature and humidity.

(6) Pressure of the mixture of exhaust and dilution air entering the CVS metering device, the pressure increase across the device, and the temperature at the inlet. The temperature maybe recorded continuously or digitally to determine temperature variations.

(7) The number of revolutions of the positive displace-

ment pump accumulated during each test phase while exhaust samples are being collected. The number of standard cubic feet metered by a critical flow venturi during each test phase would be the equivalent record for a CFV-CVS.

(8) The humidity of the dilution air.

NOTE: If conditioning columns are not used (see §86.1322 and §86.1344) this measurement can be deleted. If the conditioning columns are used and the dilution air is taken from the test cell, the ambient humidity can be used for this measurement.

[(9) The temperature of the gas flowing in the heated sample line before the heated filter, and also before the HFID, and the temperature of the control system of the heated hydrocarbon detector (for diesel engines only).]

(10) Integrated brake horsepower-hours for each test phase.

(11) Record engine torque and engine rpm continuously. The maximum time interval between recorded data points is one second.

(12) Total number of hours of operation accumulated on the engine after completing the test sequence described in Figure N83-[13].

[(13) Additional required records for diesel engines.

(i) Pressure and temperature of the dilute exhaust mixture and secondary-dilution air in the case of a double-dilution system at the inlet to the respective gas meter(s) used for particulate sampling.

(ii) The temperature of the dilute exhaust mixture immediately before the particulate filter.

(iii) Gas meter readings at the start of each sample period and at the end of each sample period.

(iv) The stabilized pre-test weight and post-test weight of each particulate sample filter.

(v) The temperature and humidity of the ambient air in which the particulate filters were stabilized.]

§86.1344-83 Calculations; exhaust emissions.

(a) The final reported transient emission test results shall be computed by use of the following formula:

$$A_{wm} = \frac{1/7(g_C) + 6/7(g_H)}{1/7(BHP\text{-}HR_C) + 6/7(BHP\text{-}HR_H)}$$

Where:

A_{wm} = Weighted mass emission level (HC, CO, CO_2, or NOx, [or particulate (diesels only)]) in grams per brake horsepower hour.

g_C = Mass emission level in grams, measured during the cold start test.

g_H = Mass emissions level in grams, measured during the hot start test.

$BHP\text{-}HR_C$ = Total brake horsepower-hour (brake horsepower) integrated with respect to time) for the cold start test.

$BHP\text{-}HR_H$ = Total brake horsepower-hour (brake horsepower) integrated with respect to time) for the hot start test.

(b) The mass of each pollutant for the cold start test and the hot start test is determined from the following equations:

(1) Hydrocarbon mass:

$$HC_{mass} = V_{mix} \times Density_{HC} \times (HC_{conc}/1,000,000)$$

(2) Oxides of nitrogen mass:

$$NOx_{mass} = V_{mix} \times Density_{NO_2} \times K_H \times (NOx_{conc}/1,000,000)$$

(3) Carbon monoxide mass:

$$CO_{mass} = V_{mix} \times Density_{CO} \times (CO_{conc}/1,000,000)$$

(4) Carbon dioxide mass:

$$CO_{2mass} = V_{mix} \times Density_{CO_2} \times (CO_{2conc}/100)$$

[(5) Diesel particulate mass:

$$M_p = V_{mix} \times \frac{M_{P_f}}{V_{S_f}} \]$$

(c) Meaning of symbols:

(1) HC_{mass} = Hydrocarbon emissions, in grams per test phase.

Density = Density of hydrocarbons is 16.33 g/ft^3 (0.5767 kg/m^3), assuming an average carbon to hydrogen ratio of 1:1.85, at 68°F (20°C) and 760 mmHg (101.3 kPa) pressure.

HC_{conc} = Hydrocarbon concentration of the dilute exhaust sample corrected for background, in ppm carbon equivalent, i.e., equivalent propane X 3.

$$HC_{conc} = HC_e - HC_d[1 - (1/DF)]$$

HC_e = Hydrocarbon concentration of the dilute exhaust sample or, for diesel, average hydrocarbon concentration of the dilute exhaust sample as calculated from the integrated HC traces, in ppm carbon equivalent.

HC_d = Hydrocarbon concentration of the dilution air as measured, in ppm carbon equivalent.

(2) NOx_{mass} = Oxides of nitrogen emissions, in grams per test phase.

$Density_{NO2}$ = Density of oxides of nitrogen is 54.16 g/ft^3 (1.913 kg/m^3), assuming they are in the form of nitrogen dioxide, at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

NOx_{conc} = Oxides of nitrogen concentration of the dilute exhaust sample corrected for background, in ppm.

$$NOx_{conc} = NOx_e - NOx_d [1 - (1/DF)]$$

where:

NOx_e = Oxides of nitrogen concentration of the dilute exhaust sample as measured, in ppm.

NOx_d = Oxides of nitrogen concentration of the dilute air as measured, in ppm.

(3) CO_{mass} = Carbon monoxide emissions, in grams per test phase.

$Density_{CO}$ = Density of carbon monoxide is 32.97 g/ft^3 (1.164 kg/m^3), at 68°F (20°C) and 760 mm Hg (101.3 kPa) pressure.

CO_{conc} = Carbon monoxide concentration of the dilute exhaust sample corrected for background, water vapor, and CO_2 extraction, in ppm.

$$CO_{conc} = CO_e - CO_d [1 - (1/DF)]$$

where:

CO_e = Carbon monoxide concentration of the dilute exhaust sample volume corrected for water vapor and carbon dioxide extraction, in ppm. The calculation assumes the carbon to hydrogen ratio of the fuel is 1:1.85.

$$CO_e = [1 - 0.01925CO_{2e} - 0.000323R]CO_{em}$$

Where:

CO_{em} = Carbon monoxide concentration of the dilute exhaust sample as measured, in ppm.

CO_{2e} = Carbon dioxide concentration of the dilute exhaust sample, in percent.

R = Relative humidity of the dilution air, in percent (see §86.1342).

CO_d = Carbon monoxide concentration of the dilution air corrected for water vapor extraction, in ppm.

$CO_d = (1 - 0.000323R)CO_{dm}$

Where:

CO_{dm} = Carbon monoxide concentration of the dilution air sample as measured, in ppm.

NOTE: If a CO instrument which meets the criteria specified in §86.1311 is used and the conditioning column has been deleted, CO_{em} can be substituted directly for CO_e and CO_{dm} can be substituted directly for CO_d.

(4) CO_{2mass} = Carbon dioxide emissions, in grams per test phase.

$Density_{CO2}$ = Density of carbon dioxide is 51.85 g/ft^3 (1.843 kg/m^3) at 68°F (20°C) and 760 mmHg (101.3 kPa) pressure.

CO_{2conc} = Carbon dioxide concentration of the dilute exhaust sample corrected for background, in percent.

$CO_{2conc} = CO_{2e} - CO_{2d}[1 - (1/DF)]$

Where:

CO_{2d} = Carbon dioxide concentration of the dilution air as measured, in percent.

[(5) M_p = Mass of particulate determined in grams per test phase.

M_{p_f} = Mass of particulate per test on the exhaust filter (or filters if a back-up is necessary. See § 86.1310(c)), grams.

V_{s_f} = Total volume of sample removed from the primary dilution tunnel, cubic feet at standard conditions.

(i) For a single-dilution system:

$$V_{s_f} = \frac{V_{a_s} \times (P_B + P_{i_s}) \times 528°R}{T_{i_s} \times 760 \text{ mmHg}}$$

where:

V_{a_s} = actual volume of dilute sample removed from the primary-dilution tunnel, cubic feet.

PB = barometric pressure, mmHg.

P_{i_s} = pressure elevation above ambient measured at the inlet to the dilute exhaust sample gas meter, mmHg. For most gas meters with unrestricted discharge P_{i_s} is negligible and can be assumed = 0.

T_{i_s} = average temperature of the dilute exhaust sample at the inlet to the gas meter, °R.

NOTE: V_{s_f} may require correction according to §86.1320-83(f).

(ii) For a double-dilution system:

$$V_{s_f} = V_{v_f} - V_{p_f}$$

where:

$$V_{v_f} = \frac{V_{a_v} \times (P_B + P_{i_v}) \times 528°R}{T_{i_v} \times 760 \text{ mmHg}}$$

V_{a_v} = actual volume of double diluted sample which passed through the particulate filter, cubic feet.

P_B = barometric pressure, mmHg.

P_{i_v} = pressure elevation above ambient measured at the inlet to the sample gas meter located at the exit side of the secondary dilution tunnel, mmHg. For most gas meters with unrestricted discharge P_{i_v} is negligible and can be assumed = 0.

T_{i_v} = average temperature of the dilute exhaust sample at the inlet to the exit side gas meter, °R.

$$V_{P_f} = \frac{V_{a_p} \times (P_B + P_{i_p}) \times 528°R}{T_{i_p} \times 760 \text{ mmHg.}}$$

V_{a_p} = actual volume of secondary dilution air, cubic feet.

P_B = barometric pressure, mmHg.

P_{i_p} = pressure elevation above ambient measured at the inlet to the sample gas meter located at the inlet side of the secondary dilution tunnel, mmHg. For most gas meters with unrestricted discharge P_{i_p} is negligible and can be assumed = 0.

T_{i_p} = average temperature of the dilute exhaust sample at the inlet to the inlet side gas meter, °R.

NOTE: Both V_{v_f} and V_{P_f} may require correction according to §86.1320-83(f). These corrections must be applied before V_{s_f} is determined.

NOTE. The background particulate level inside the dilution air filter box at EPA is very low. This particulate level will be assumed = 0, and background particulate samples will not be taken with each exhaust sample. If is recommended that background particulate checks be made periodically to verify the low level. Any manufacturer may make the same assumption without prior EPA approval.]

[(6)] $DF = 13.4[CO_{2e} + (HC_e + CO_e) \times 10^{-4}]$

K_H = Humidity correction factor.

$K_H = 1/[1-0.0047(H-75)]$

for SI units = $1/[1-0.0329(H-10.71)]$

Where:

H = Absolute humidity in grains (grams) of water per pound (kilogram) of dry air.

$H = [(43.478)R_a \times P_d]/[P_B - (P_d \times R_a/100)]$

for SI units: $H = [(6.2111)R_a \times P_d]/[P_B - (P_d \times R_a/100)]$

R_a = Relative humidity of the ambient air, in percent.

P_d = Saturated vapor pressure, in mmHg (kPa) at the ambient dry bulb temperature.

P_B = Barometric pressure, in mm Hg (kPa).

Vmix = Total dilute exhaust volume in cubic feet per test phase corrected to standard conditions (528°R (293K) and 760 mm Hg (101.3 kPa)).

For PDP-CVS, V_{mix} is:

$$V_{mix} = V_o \times \frac{N(P_B - P_4)(528^\circ R)}{(760\ mmHg)(T_p)}$$

for SI units,

$$V_{mix} = V_o \times \frac{N(P_B - P_4)(293K)}{(101.3\ kPa)(T_p)}$$

Where:

V_o = Volume of gas pumped by the positive displacement pump, in cubic feet (cubic meters) per revolution. This volume is dependent on the pressure differential across the positive displacement pump.

N = Number of revolutions of the positive displacement pump during the test phase while samples are being collected.

P_B = Barometric pressure, in mm Hg (kPa)

P_4 = Pressure depressions below atmospheric measured at the inlet to the positive displacement pump, in mm Hg (kPa) (during an idle mode).

T_p = Average temperature of dilute exhaust entering positive displacement pump during test, °R (K).

(d) Sample calculation of mass values of exhaust emissions:

(1) Assume the following test results:

	Cold Start Cycle Test Results	Hot Start Cycle Test Results
V_{mix}	6924 ft^3	6873 ft^3
R	30.2%	30.2%
R_a	30.2%	30.2%
P_B	735 mmHg	735 mmHg
P_d	22.676 mmHg	22.676 mmHg
HC_e	132.1 ppmC equiv.	86.13 ppmC equiv.
NOx_e	7.86 ppm	10.98 ppm
CO_{em}	171.22 ppm	114.28 ppm
CO_{2e}	0.178%	0.381%
HC_d	3.60 ppmC equiv.	8.70 ppmC equiv.
NOx_d	0.0 ppm	0.10 ppm
CO_{dm}	0.89 ppm	0.89 ppm
CO_{2d}	0.0%	0.038%
$[V_{s_f}$	60 ft^3	59.8 $ft^3]$
$[M_{P_f}$	0.006251 gm	0.005812 gm$]$
BHP-Hr	0.259	0.347

Then:

Cold Start Test

$$H = [(43.478)(30.2)(22.676)]/[735 - (22.676)(30.2)/100]$$

$$= 41 \text{ grains of water per pound of dry air.}$$

$$K_H = 1/[1 - 0.0047(41 - 75)] = 0.862$$

$$CO_e = [1 - 0.01925(0.178) - 0.000323(30.2)]171.22$$

$$= 169.0 \text{ ppm}$$

$$CO_d = [1 - 0.000323(30.2)]0.89 = 0.881 \text{ ppm}$$

$$DF = 13.4/[0.178 + (132.1 + 169.0)(10^{-4})] = 64.265$$

$$HC_{conc} = 132.1 - 3.6[1-(1/64.265)] = 128.6 \text{ ppm}$$

$$HC_{mass} = (6924(16.33)(128.6/1,000,000) = 14.53 \text{ grams}$$

$$NOx_{conc} = 7.86 - 0.0[1 - (1/64.265)] = 7.86 \text{ ppm}$$

$$NOx_{mass} = 6924(54.16)(0.862)(7.86/1,000,000) = 2.54 \text{ grams}$$

$$CO_{conc} = 169.0 - 0.881[1 - (1/64.265)] = 168.0 \text{ ppm}$$

$$CO_{mass} = 6924(32.97)(168.0/1,000,000) = 38.35 \text{ grams}$$

$$CO_{2conc} = 0.178 - 0[1 - 1/64.265)] = 0.178\%$$

$$CO_{2mass} = 6924(51.85)(.178/100) = 639 \text{ grams}$$

$$[M_p = 6924(0.006251)/60 = 0.721 \text{ grams}]$$

Hot Start Test

Assume similar calculations result in the following:

$$HC_{mass} = 8.72 \text{ grams}$$

$$NOx_{mass} = 3.49 \text{ grams}$$

$$CO_{mass} = 25.70 \text{ grams}$$

$$CO_{2mass} = 1226 \text{ grams}$$

$$[M_p = 0.668 \text{ grams}]$$

(2) Weighted mass emission results:

$$HC_{wm} = \frac{1/7(14.53) + 6/7(8.72)}{1/7(0.259) + 6/7(0.347)}$$

$$= 28.6 \text{ grams/BHP-HR}$$

$$NOx_{wm} = \frac{1/7(2.54) + 6/7(3.49)}{1/7(0.259) + 6/7(0.347)}$$

$$= 10.0 \text{ grams/BHP-HR}$$

$$CO_{wm} = \frac{1/7(38.35) + 6/7(25.70)}{1/7(0.259) + 6/7(0.347)}$$

$$= 82.2 \text{ grams/BHP-HR}$$

$$CO_{2wm} = \frac{1/7(639) + 6/7(1226)}{1/7(0.259) + 6/7(0.347)}$$

$$= 3415 \text{ grams/BHP-HR}$$

$$\left[M_{pwm} = \frac{1/7(0.721) + 6/7(0.668)}{1/7(0.259) + 6/7(0.347)}\right.$$

$$\left. = 2.02 \text{ grams/BHP-HR}\right]$$

(e) The final reported brake-specific fuel consumption (BSFC) shall be computed by use of the following formula:

$$BSFC = \frac{1/7(M_C) + 6/7(M_H)}{1/7(BHP\text{-}HR_C) + 6/7(BHP\text{-}HR_H)}$$

Where:

BSFC = brake-specific fuel consumption in pounds of fuel per brake horsepower-hour (lbs/BHP-HR).

M_C = mass of fuel, in pounds, used by the engine during the cold start test.

M_H = mass of fuel, in pounds, used by the engine during the hot start test.

$BHP\text{-}HR_C$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the cold start test.

$BHP\text{-}HR_H$ = total brake horsepower-hours (brake horsepower integrated with respect to time) for the hot start test.

(f) The mass of fuel for the cold start and hot start test is determined from the following equation:

$$M = (G_s/R)(1/453.6)$$

(g) Meaning of symbols:

M = Mass of fuel, in pounds, used by the engine during the cold or hot start test.

G_s = Grams of carbon measured during the cold or hot start test.

$$G_s = [12.011/(12.011 + \alpha(1.008))]HC_{mass} + 0.429CO_{mass} + 0.273\ CO_{2mass}$$

where:

HC_{mass} = Hydrocarbon emissions, in grams for cold or hot start test.

CO_{mass} = Carbon monoxide emissions, in grams for cold or hot start test.

CO_{2mass} = Carbon dioxide emissions, in grams for cold or hot start test.

α = The measured hydrogen to carbon ratio of the fuel.

R = The grams of carbon in the fuel per gram of fuel

$$R = 12.011/[12.011 + \alpha(1.008)]$$

(h) Sample calculation of brake-specific fuel consumption:

(1) Assume the following test results:

	Cold Start Cycle Test Results	Hot Start Cycle Test Results
BHP-HR	6.945	7.078
α	1.85	1.85
HC_{mass}	37.08 grams	28.82 grams
CO_{mass}	357.69 grams	350.33 grams
CO_{2mass}	5419.62 grams	5361.32 grams

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Then:

G_s for cold start test =
$[12.011/(12.011 + (1.85)(1.008))](37.08) + 0.429(357.69) + 0.273(5419.62) = 1665.10$ grams

G_s for hot start test =
$[12.011/(12.011 + (1.85)(1.008))](28.82) + 0.429(350.33) + 0.273(5361.32) = 1638.88$ grams

$R = 12.011/[12.011 + 1.85(1.008)] = 0.866$

$M_C = (1665.10/0.866)(1/453.6) = 4.24$ lbs

$M_H = (1638.88/0.866)(1/453.6) = 4.17$ lbs

(2) Brake-specific fuel consumption results:

$$BSFC = \frac{1/7(4.24) + 6/7(4.17)}{1/7(6.945) + 6/7(7.078)} = 0.592 \text{ lbs of fuel/BHP-HR}$$